IESO Resource & Plan Assessments Technical Paper: Hybrid Resource Portfolio Equivalency Assessment

Study of the reliability and economics of variable generation and BESS resource portfolios to meet system needs traditionally supplied by dispatchable resources

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Table of Contents

1. Executive Summary

Over the next few years, the IESO plans to procure a diverse mix of resources that includes variable generation (wind and solar), battery energy storage systems (BESS) and natural gas, to meet significant demand growth forecast in the coming decades. To help meet this growth, the Ontario government has identified nuclear generation as a strategic priority for the province's long-term needs in both its 2023 *Powering Ontario's Growth*[1] report, as well as the 2025 *Energy for Generations: Ontario's Integrated Plan to Power the Strongest Economy in the G7*.[2] Both documents highlight the Ontario government's support for additional small modular reactors (SMRs) and signal a path to a new, large-scale nuclear build at Bruce Nuclear Generating Station. This is in addition to ongoing development work to refurbish four reactors at the Pickering Nuclear Generating Station.

Integrating a large portfolio of variable generation resources – here referred to as "VG" – into the IESO-controlled grid will present challenges for system planners and operators due to the intermittent nature of the resources. However, advancements in battery technology and declining prices are providing opportunities to better utilize these resources, enhancing their performance and effective grid penetration. Deploying BESS with VG improves the overall capability and performance of both, as VG provides low-cost energy to charge the BESS, which can then shift VG to hours of higher system value. The IESO Resource & Plan Assessments Technical Paper on the effective load carrying capacity of energy storage further demonstrates the symbiotic relationship between VG and BESS.[3]

This paper explores the capability and costs of resource portfolios consisting of various VG and BESS to meet defined need profiles and compares them with combined-cycle gas turbines (CCGTs) and SMR options to meet the equivalent needs. "Hybrid resource portfolio" in the context of this paper refers to a mix of VG and BESS with maximum flexibility to integrate into the bulk system, and it does not have a specific requirement for co-location of resources. This differs from a "hybrid facility," which implies co-location of resources that are oftentimes set up behind the meter.

Two need scenarios (i.e., load profiles) were developed to study the equivalency of hybrid resource portfolios. The first – the "Peaky Need Scenario" – represents a high peak demand scenario and is based on preliminary production cost modelling (i.e., energy simulations) for the *2025 Annual Planning Outlook* (APO) without capacity expansion, which resulted in an unserved energy profile of ~5 TWh in the medium term and a peak need of ~7,300 MW. The second – the "Baseload Need Scenario" – represents a 2,000 MW baseload need profile, akin to a large baseload generation facility.

The Plexos capacity expansion model was used to develop optimal hybrid resource portfolios to supply the load under the two need scenarios. The portfolios were then tested using the Plexos production cost model, focusing on achieving energy adequacy and operational efficiency. The model

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1 Powering Ontario's Growth | ontario.ca

2 Energy for Generations: Ontario's Integrated Plan to Power the Strongest Economy in the G7 | ontario.ca

3 IESO Resource & Plan Assessments Technical Paper: Effective Load Carrying Capacity of Energy Storage

considered 13 potential wind sites and 10 potential solar sites, across 10 different weather years,[4] to capture the geographic and temporal variability in wind speed and solar intensity. The model assumes zero-loss transmission transfer capability such that the desired volumes of electricity can freely flow across the province.

Results for the two scenarios are presented below.

Table 1 | Summary of Results for Two Needs Scenarios

Need Scenario	Resource	Resource Build (MW)	Energy Need (TWh)	NPV ($2024 Billions)	% of Load Served
Peaky	Gas-Only	~8,000	5.1	31.4	100.0
	SMR-Only	~8,000		97.1 to 120.0	100.0
	VG+BESS	~13,500 to 16,800		44.1 to 52.9	99.5 to 99.98
	Gas+VG+BESS	~8,000 to 10,400		25.3 to 34.3	100.0
Baseload	Gas-Only	2,200	17.5	28.2	100.0
	SMR-Only	2,200		27.6 to 33.8	100.0
	VG+BESS	~11,300 to 15,100		37.3 to 46.8	99.7 to 99.9

For the Peaky Need Scenario, the gas-only option is estimated to cost $31 billion for an 8,000 MW build-out that achieves 100 per cent load served. The hybrid resource portfolio option is estimated to cost between $44 billion and $53 billion, with a build-out of 13,500 MW to 16,800 MW achieving 99.5 per cent to 99.98 per cent of load served.[5] This may introduce reliability risk in the province – see Section 3.4.4 for more information. Finally, in this scenario, nuclear costs range from $97 billion to $120 billion.

For the Baseload Need Scenario, nuclear generation shows economic and technical advantages for providing baseload power, especially when non-emitting generation is preferred. The SMR-only solution costs $28 billion to $34 billion for 2,200 MW of installed capacity, achieving 100 per cent load served. The gas-only option costs approximately $28 billion for 2,200 MW, also achieving 100 per cent load served.

[4] As described in more detail in Section 3.2.1, the 10 weather years are real wind and solar data collected at the sites from 1999 to 2008.
[5] As described in more detail in Section 3.4.4, percentage of load served is equal to one minus percentage of unserved energy.

Hybrid resource portfolio solutions require 11,300 MW to 15,000 MW of installed capacity to serve the Baseload Need Scenario, with costs ranging from $37 billion to $47 billion and achieving 99.7 per cent to 99.9 per cent load served.

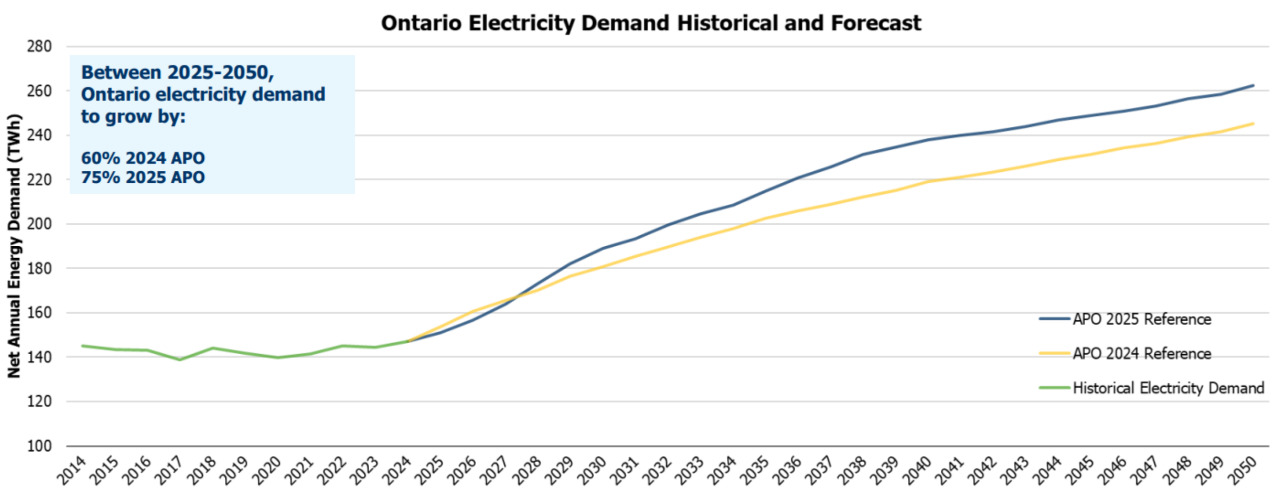
Due to the excessive overbuild required for hybrid resource portfolio solutions, a significant amount of potential energy is "curtailed" when generation capacity exceeds load and batteries are fully charged. This excess energy, not captured in the above assessment, could provide significant system value by displacing higher-cost resources. A simplistic sensitivity analysis, described in Section 6, suggests this excess energy could potentially provide tens of billions of dollars in system value.

This technical paper presents the results of a desktop-level capacity expansion and production cost modelling exercise and economic analysis. It does not constitute a plan or recommendation for a specific resource mix to meet Ontario's future electricity needs. Additionally, the study did not impose resource build limits, so the feasibility of building the resulting resource portfolios has not been considered.

2. Introduction

Ontario's electricity sector is forecast to see rapidly growing demand that is being driven by increased electrical-vehicle production/supply chain growth, strong commercial interest in building new data centres, new industrial processing methods that are fuelled with electricity, and a steady growth in population and household formation. This can be seen in Figure 1, which highlights the higher demand forecast in the 2025 APO compared with the previous outlook.

Figure 1 | Annual Energy Demand



In anticipation that an increased supply of electricity-producing resources will be required to meet this increasing demand, the Ontario government announced on Dec. 11, 2024, that it would be expanding its Long-Term 2 RFP, which had already been expected to be the largest competitive procurement in the province's history. The expanded procurement is seeking to secure up to 14 TWh of new energy-producing resources to be in service before 2034,[6] which includes non-emitting and intermittent resource types.

In addition, the Ontario government has identified a significant amount of clean, reliable baseload resources that will need to be developed in the mid-late 2030s and beyond to satisfy longer-term energy requirements. These resource options are outlined in the *Powering Ontario's Growth* plan and include new nuclear development at the Bruce nuclear site, as well as expanding the province's SMR program.

The objective of this paper is to present results of a capacity expansion and production cost modelling exercise, and an economic assessment comparing hybrid resource portfolio combinations of wind, solar and BESS with gas generators and SMRs, as alternatives to reliably supply demand under the following needs scenarios:

[6] Ontario Expands Largest Competitive Energy Procurement in Province's History | Ontario Newsroom

1) **Peaky Need Scenario** – As described in more detail in Section 4, a medium-term energy need profile from the preliminary 2025 APO energy simulations will be used to define the system need and size of the resource candidates under this scenario.
2) **Baseload Need Scenario** – As described in more detail in Section 5, a 2,000 MW baseload need will be used to define the system need as this can approximate the size of a large baseload facility.

It should be emphasized that this document is not a plan, nor does it constitute a recommendation or endorsement of any resource, resource portfolio or technology. Instead, this technical paper explores new modelling methods and techniques – specifically for VG and BESS hybrid resource portfolios – to document and share the results and solicit feedback on areas that can be improved. Ultimately, it is anticipated that the results from this study (and subsequent work) can begin to help inform Ontario's future electricity planning practices, modelling capabilities and resource procurement initiatives.

3. Assumptions and Modelling Approach/Limitations

3.1 Global Assumptions

The following set of assumptions apply across the scope of the analysis, and are not specific to individual resource types:

- The IESO utilized Energy Exemplar's Plexos modelling software to produce cost-optimized resource portfolios required to serve load under the two need scenarios.
- Resource technical life and build times are based on the U.S. National Renewable Energy Laboratory's (NREL) 2024 Electricity Annual Technology Baseline (ATB) Excel Workbook (moderate scenario).
- A perfect "copper plate" approach assumes the system has sufficient transmission transfer capability to ensure the desired volumes of electricity can be freely transported across the province with no line losses.
- The same load profiles are used for the duration of the economic planning horizon, which in the Peaky Need Scenario has a peak demand of 7,311 MW and an energy demand of 5.1 TWh, and in the Baseload Need Scenario is a flat 2,000 MW profile.
- The analysis assumes no build limits on new resources.

3.2 Resource-Specific Assumptions

The following set of assumptions are specific to individual resource types:

3.2.1 VG Resource Assumptions

- Ten years of correlated, historical solar and wind profiles (1999-2008) across 13 potential wind sites and 10 potential solar sites, were used to create 10 different weather years. Weather year 1 will use 1999 resource profiles, weather year 2 will use 2000 resource profiles, and so on until weather year 10 uses 2008 resource profiles. More details are provided in Section 3.4.2 Weather Data.

3.2.2 BESS Assumptions

- Four-, six-, eight- and 10-hour duration lithium-ion candidate resource options.
- Batteries can charge from the existing system when there is no system need (i.e., demand is fully met) and there also exists excess gas generation capacity.

3.2.3 SMR Assumptions

- SMRs can be "right sized" to meet the precise peak need requirement.
- SMR cost estimate ranges were developed with NREL's 2024 Electricity ATB Excel Workbook (moderate scenario) forming the low end of the range, and the Tennessee Valley Authority's

(TVA) *2025 Integrated Resource Plan* (IRP) estimate of an nth-of-a kind light-water SMR forming the high end.
- SMR costs from NREL commence in 2030 – these 2030 costs were what was used to form the low end of the range.
- SMRs were modelled as a dispatchable resource and could respond to demand and market signals with maximum operational flexibility.

3.2.4 Gas Assumptions

- Natural gas price forecast at the Dawn Hub is as per the Sproule Outlook.
- A carbon price assumption of $170/tCO2e is used and is held constant in nominal dollars for the forecast period.
- The Output Based Pricing System regulations threshold/allowance for new gas generation is assumed to be zero tonnes per gigawatt-hour.

3.3 Financial Assumptions

- The financial assumptions underpinning the analysis do not include the potential cost impacts of future government policies on emissions or procurements (e.g., Clean Electricity Regulation, municipal approvals requirements, etc.).
- The levelized resource costs are based on NREL's 2024 Electricity ATB Excel Workbook (moderate scenario) converted to CAD $2024 (except for the high-end range of the SMR costs coming from the TVA's 2025 IRP).
- All resource candidate costs are amortized over 60 years to align with the technical life of an SMR. To accommodate for the difference in life between VGs, BESS, gas resources and SMRs, it is assumed that new VGs, BESS and gas resources are built at the end of the economic life of the previous ones.
- All NPV calculations assume a 4 per cent real social discount rate.
- On the high end of valuing excess energy from VG curtailment, the average forecast Market Clearing Price (MCP) from the 2025 APO is applied to the curtailed energy and an NPV is calculated over the 60-year amortization period. Given the 2025 APO only goes out to 2050, the 2050 MCP is applied to the remainder of the 60-year amortization period.

3.4 Modelling Approach & Limitations

3.4.1 Modelling Solutions that include VG and BESS Hybrid Resource Portfolios

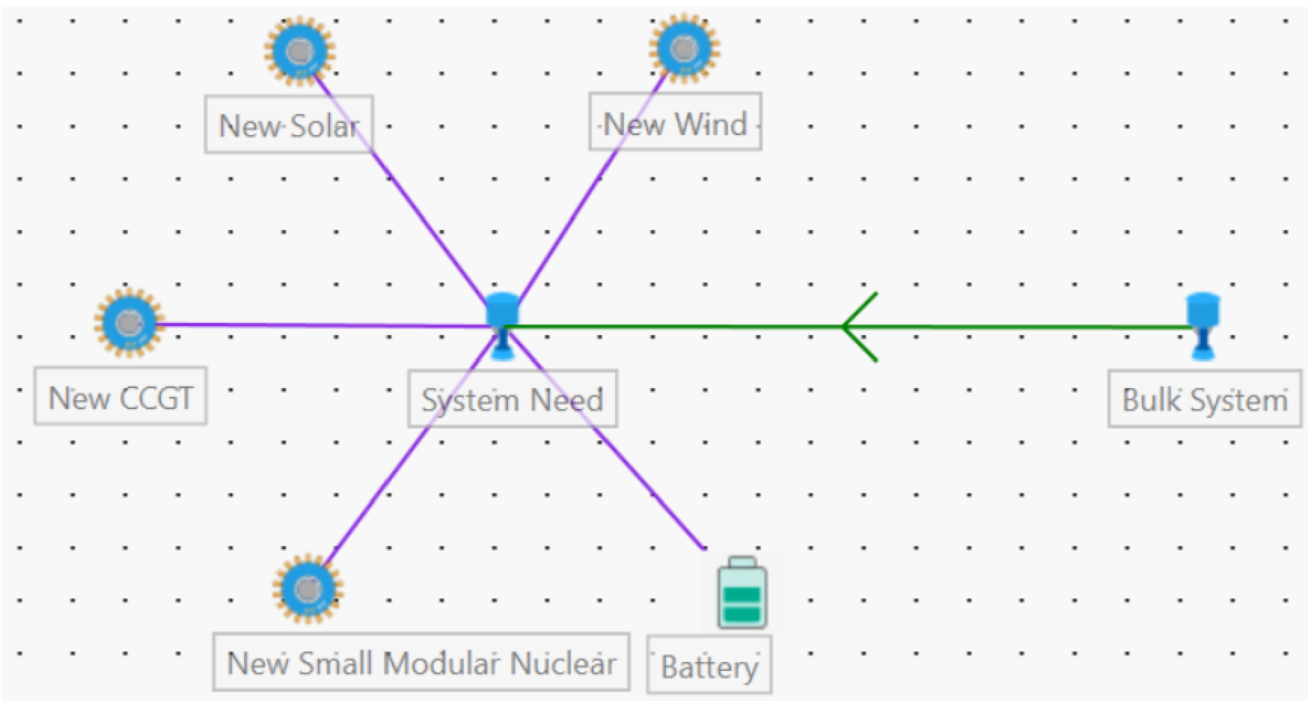
A specialized Plexos-based optimization tool was developed for this study to aid in creating non-emitting, VG and BESS hybrid resource portfolios capable of meeting the load profiles outlined in Section 1 and detailed further in Sections 4 and 5. This tool is designed to solve the capacity expansion (LT) module on an 8,760-hour basis, ensuring that the resulting resource portfolio can provide high energy reliability in the production cost (ST) module. The goal is to achieve zero or near-zero unserved energy (or 100 per cent load served) without artificially inflating reserve margins.

To meet these ambitious targets, the tool employs a pragmatic approach by modelling the existing electricity system in a simplified manner. Instead of representing the system as a complex network of dynamic electricity resources and load customers, it is modelled as deterministic, hourly profiles wherever possible. This allows the LT model to operate on an hourly granularity using daily, 24-hour load duration curves, maintaining reasonable computation requirements and run times. Consequently, the system can be designed to be 100 per cent or nearly 100 per cent adequate without the need for excessive overbuilding.

However, this approach has limitations and is not suitable for many power system studies or planning exercises. For instance, it does not adequately capture the dispatchability (e.g., gas turbines) and storage capability (e.g., hydroelectric reservoirs) of existing system resources. While such resources can be included in the model, this analysis aimed for simplicity to avoid the additional computational resources required by more complex models, which would negate the benefits of high temporal granularity.

Figure 2 below illustrates this simplified model of an electricity system, highlighting the relationship between the "System Need," the "Bulk System" and various potential resource candidates.

Figure 2 | Visualization of a Simple Electricity System Model



In this model, System Need is represented as a single node with an 8,760-hour load profile, which provides a granular, hour-by-hour representation of energy demand across the entire year. This detailed load curve captures daily and seasonal variations in electricity needs, allowing the LT model to solve capacity expansion with an accurate understanding of demand fluctuations.

The System Need node is connected to a Bulk System node by a transmission line (green arrow). At the Bulk System node, there is an infinite energy market supplying low-cost electricity. The transmission line's transfer capability is used to represent an 8,760-hour profile of the excess capacity of the Ontario gas fleet (i.e., installed capacity minus hourly output of the Ontario gas fleet). This setup simulates the excess capacity of the existing Ontario gas fleet to produce electricity for charging batteries during low-demand hours, relevant only in the Peaky Need Scenario. In the Baseload Need Scenario, the line and Bulk System node are excluded from the modelling.

Finally, the System Need node is connected to various capacity expansion resource candidates, which in this study could include combinations of new BESS, solar, wind, CCGTs and SMRs. The different electricity resources provide a mix of options for the model to meet energy demand. For wind and solar resource candidates, multiple potential locations and weather years were considered, as described in Section 3.4.2 below.

3.4.2 Weather Data

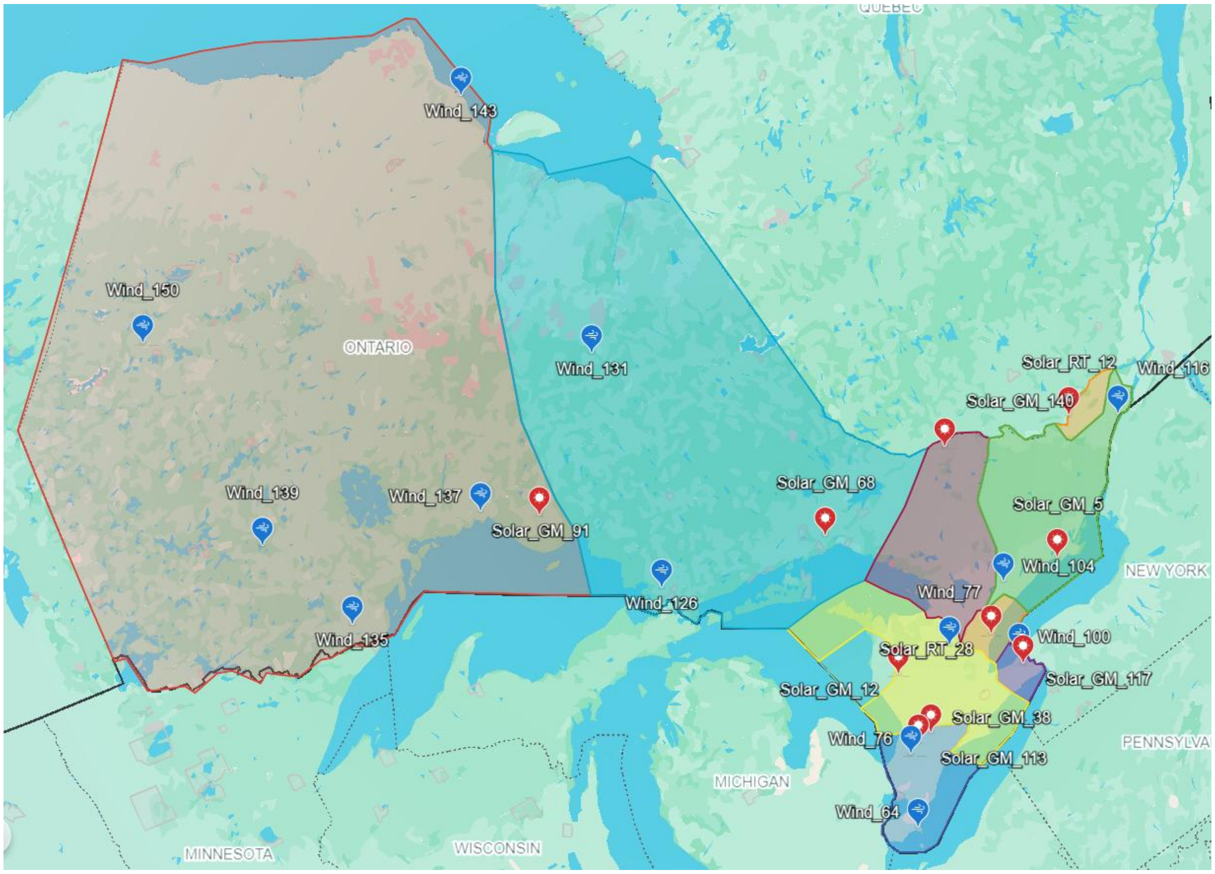
Wind Profiles – The IESO retained AWS Truepower to generate hourly wind profiles at operational and hypothetical plants across Ontario as part of the *Pathways to Decarbonization* (P2D) study. The results of that study[7] were used to inform this one. The hourly net power generation profiles were simulated for the 1988-2018 period across 63 operational and 87 hypothetical plants within the IESO domain (150 total). From the 150 profiles developed by AWS, 13 were selected as being the most representative profiles for potential wind development sites throughout Ontario's 10 zones. These 13 profiles are the same as those used in the IESO's P2D study and form the wind resource options that inform this study.

Solar Profiles – AWS Truepower was also engaged by the IESO to develop solar PV plant output data for Ontario. The hourly net power generation profiles were simulated for the 1999-2008 period across 200 hypothetical solar plants. From the 200 profiles developed by AWS, 10 were selected as being the most representative profiles for potential solar development sites throughout Ontario's 10 zones. All the profiles were based on ground-mounted solar technology, except for the Toronto and Ottawa zonal profiles, which assumed rooftop technology.

A map of the 13 wind and 10 solar resource candidate sites are presented in Figure 3.

[7] P2D Appendix E - UL-IESO Wind Profiles

Figure 3 | Wind and Solar Resource Candidate Sites



3.4.3 Modelling Dispatchable Resource Solutions

Stand-alone dispatchable resource solutions (SMR-only and gas-only) did not utilize the Plexos tool as there is no portfolio of resources to optimize. For these resources, a system overbuild factor of 10 per cent was assumed to meet 100 per cent of the load served to account for any lost generation from outages, as well as lower summer effective capacity. A spreadsheet exercise was conducted to perform the analysis.

3.4.4 Per Cent Load Served

This technical paper uses per cent load served (defined as one minus per cent unserved energy) as the measure to assess the reliability of the resource portfolios. Per cent load served tells us how much of the load can be served, which is different than the established NERC[8] criteria for assessing system adequacy, which is based on how often the load can be served (i.e. a minimum loss of load expectation ("LOLE") of 1 day in 10 years is considered adequate). Since per cent load served is not the established NERC criteria, there is no official threshold for what is adequate. However, if a similar threshold as NERC's LOLE of 1 day in 10 years was applied, a system with 99.97 per cent load served would likely be considered adequate, and anything less would require backup resources like demand side measures.[9]

[8] North American Electric Reliability Corporation

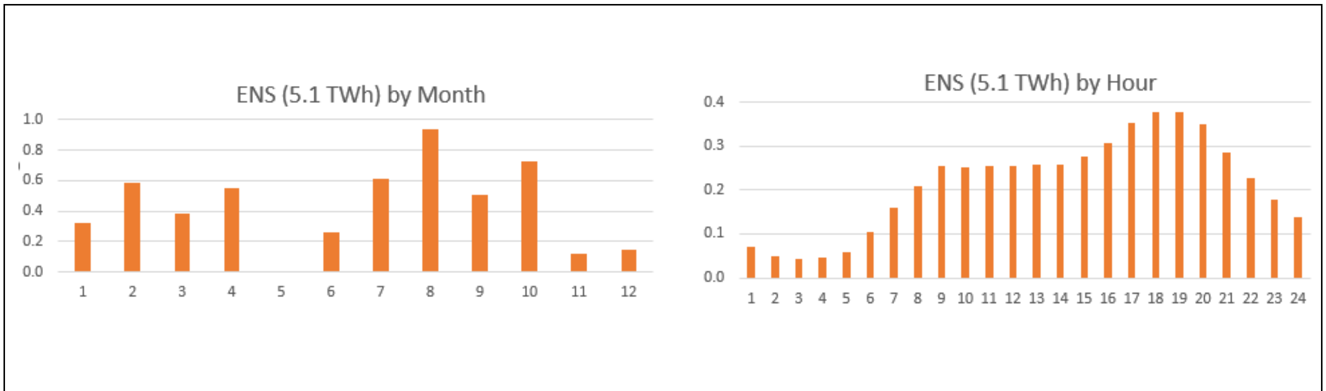
[9] Demand side measures represent approximately 6.5% of the IESO's available resources for meeting 2025 summer peak load

4. Solving for the Peaky Need Scenario

4.1 Need Profile

The need profile for the Peaky Need Scenario is based on a medium-term year's unserved energy profile from preliminary 2025 APO energy simulations, without allowing for new-build resource expansion. This amounts to a total of 5.1 TWh of additional energy with a peak requirement of 7,311 MW. Figure 4 below highlights some of the characteristics of this unserved energy (i.e., energy not served, or ENS).

Figure 4 | ENS Characteristics



As can be seen in Figure 4, the 5.1 TWh need profile has intra-month and intra-day variability. The monthly chart shows the need peaking in the summer with most of the annual need occurring between July and October. The 8,760-hour chart captures an evening peak with a morning and evening ramp. The following subsections will explore three sets of resource options that have been developed and costed to meet this need profile.

4.2 Dispatchable Resource Solutions

The first set of resource candidates considered to solve the Peaky Need Scenario were dispatchable stand-alone resource options – CCGTs and SMRs. For both resource types, it was assumed that a 10 per cent capacity overbuild is required to achieve 100 per cent of load served, where the percentage of load served is defined as one minus the percentage of unserved energy. As such, a total resource build of 8,042 MW of either resource is required to fully serve the Peaky Need Scenario. These assumptions and resulting costs are provided in Table 2.

Table 2 | Gas or SMR Resource Solution – Peaky Need Scenario

Resource	Capacity Need (MW)	System Overbuild Factor	Resource Build (MW)	Energy Need (TWh)	NPV 2024 – 2090 in $2024 Real in Billion	% of Load Served
CCGT	7,311	10%	8,042	5.1	31.4	100.00
SMR	7,311	10%	8,042	5.1	97.1 to 120	100.00

As can be seen from Table 2, the cost of a gas generation-only solution in the Peaky Need Scenario is roughly $31 billion. This can be contrasted with the cost of an SMR-only solution to service the same need, which ranges between $97 billion to $120 billion. Thus, when comparing stand-alone resource options, a gas-only resource solution is approximately one-third (or less) the cost of an SMR-only resource solution. Quite clearly, the SMR-only solution is ill-suited for this scenario as the need is "peaky" and varies by season. To operate an SMR at an annual capacity factor of roughly 8 per cent presents astronomical costs on a per megawatt-hour basis.[10] It should be noted, however, that the profile in the Peaky Need Scenario already assumes significant large nuclear and SMR generation in the base case, so baseload power is already being provided by these resources. Section 5 captures the value that SMRs provide.

4.3 VG and BESS Hybrid Resource Portfolio Solutions

The next set of resource candidates used to solve the Peaky Need Scenario were hybrid resource portfolio options – a portfolio of batteries combined with VG options. The optimal mix of these resources was solved using Plexos for 10 different weather years to provide a range of weather-dependant portfolios that serve the need. The portfolio builds and costs for the 10 weather years are provided in Table 3.

[10] SMRs are operationally constrained to provide baseload power; however, no value of this excess production from the Peaky Need Scenario is captured in the results.

Table 3 | BESS + Wind + Solar Resource Solution – Peaky Need Scenario

Weather Year	BESS (MW)	BESS (MWh)	Wind (MW)	Solar (MW)	Total (MW)	Excess Energy (TWh)*	NPV 2024 – 2090 in $2024 Real in Billion	% of Load Served
1	4,161	27,492	5,184	5,594	14,940	27.7	50.1	99.81
2	3,069	18,028	9,019	2,941	15,029	38.1	46.1	99.98
3	4,401	27,170	5,933	6,431	16,766	31.8	46.0	99.80
4	2,927	16,468	9,519	3,941	16,387	41.0	47.3	99.81
5	3,244	20,358	8,790	3,821	15,854	36.7	48.4	99.75
6	4,089	28,144	5,034	5,462	14,584	25.6	48.3	99.81
7	3,947	28,510	6,396	4,591	14,934	30.4	49.3	99.88
8	3,402	20,910	6,468	3,676	13,546	29.2	48.4	99.50
9	3,473	22,758	6,174	4,454	14,101	27.5	44.1	99.52
10	4,491	39,284	6,801	4,132	15,433	29.9	52.9	99.61

***NOTE:** No value of excess energy production is explicitly captured in these results; however, Section 6 discusses the implications of assigning excess energy a value.

As shown in Table 3, the VG + BESS hybrid resource portfolio is sensitive to the weather year selected. On a cost basis, if weather year 8 is used, approximately 14,100 MW is required to service the need at a cost of ~$44 billion. This can be contrasted with weather year 10, wherein approximately 15,400 MW is required to service the same need at a cost of ~$53 billion (more than 20 per cent higher).

Under all the weather years, the percentage of load served is reasonably high, ranging from 99.50 per cent in weather year 8 to 99.98 per cent in weather year 3.

4.4 Dispatchable + Hybrid Resource Portfolio Solutions

The final set of resource candidates used to solve the Peaky Need Scenario were dispatchable + hybrid resource portfolio options. This allows Plexos to select a portfolio of resources from the following candidates:

- Four-, six-, eight- and 10-hour BESS
- Wind
- Solar
- CCGTs

- SMRs

The portfolio of resources built (and the total costs) for the 10 different weather years are presented in Table 4.

Table 4 | BESS + Wind + Solar + Gas + SMR Resource Solution – Peaky Need Scenario

Weather Year	BESS (MW)	BESS (MWh)	Wind (MW)	Solar (MW)	CCGT (MW)	SMR (MW)	Total (MW)	Excess Energy (TWh)*	NPV 2024 – 2090 in $2024 Real in Billion	% of Load Served
1	2,273	9,092	2,234	1,230	3,851	-	9,688	9.2	32.7	100.00
2	0	0	3,852	886	3,473	-	8,211	14.8	26.8	100.00
3	0	0	3,366	426	4,506	-	8,298	12.6	25.3	100.00
4	1,741	8,382	223	-	6,056	-	8,020	10.8	26.8	100.00
5	1,784	7,464	1,076	614	4,604	-	9,537	8.8	31.1	100.00
6	1,737	6,948	2,943	1,320	4,406	-	10,406	11.4	34.3	100.00
7	2,235	8,940	2,559	1,080	3,806	-	9,680	10.1	30.5	100.00
8	1,917	7,668	2,899	908	3,901	-	9,625	10.5	31.5	100.00
9	2,100	8,400	2,186	1,372	4,114	-	9,772	9.1	30.3	100.00
10	1,753	7,012	2,876	539	4,037	-	9,205	10.2	29.7	100.00

***NOTE:** No value of excess energy production is explicitly captured in these results; however, Section 6 discusses the implications of assigning excess energy a value.

As shown in Table 4, a portfolio of resources that includes both VG + BESS and CCGT (and excludes SMR) is selected in each weather year. As with the previous options, the specific resource mix is sensitive to the weather year selected. On a cost basis, if weather year 3 is used, approximately 8,300 MW is required to service the need at a cost of ~$25 billion. This can be contrasted with weather year 6, wherein approximately 10,400 MW is required to service the same need at a cost of ~$34 billion (more than 35 per cent higher). These resource portfolios are both less costly and provide better percentage of load served (100.00 per cent for each weather year) than the VG + BESS hybrid resource portfolio solutions presented in Section 4.3.

4.5 Summary

The Peaky Need Scenario is based on a medium-term unserved energy profile from the preliminary 2025 APO energy simulations, without allowing for new-build resource expansion. A total of 5.1 TWh of additional energy with a peak requirement of 7,311 MW was used, with the profile having both intra-month and intra-day variability. Three sets of resource candidates were explored to meet the profile:

1. **Dispatchable Resources** – able to fully meet the need (100 per cent of load served), with the gas-only option ($31.4 billion) being substantially less expensive than the SMR-only option ($97 billion to $120 billion).
2. **Hybrid Resource Portfolio** – meets the need in excess of 99.50 per cent of load served, with costs ranging from $44 billion to $53 billion, depending on the weather year used.
3. **Dispatchable + Hybrid Resource Portfolios** – able to fully meet the need (100 per cent of load served), with costs ranging from $25 billion to $34 billion. This option is more economic than the gas-only option in seven of the 10 weather years utilized.

As noted throughout this section, no value of excess energy production is explicitly captured in these results; however, Section 6 discusses the potential implications of assigning excess energy a value. Given this qualification, the third option stands to be the optimal supply mix in terms of cost and load-serving ability to meet the Peaky Need Scenario.

5. Solving for the Baseload Need Scenario

5.1 Need Profile

Baseload resources can generate a constant, steady supply of electricity – 24 hours a day, seven days a week. The output of these resources is consistent and reliable, but it rarely changes. Because they can meet these operational requirements, nuclear plants are considered a baseload resource and are typically used first to meet Ontario's energy needs.[11]

This section compares the hybrid resource portfolio of options with CCGTs and/or SMRs to meet a 2,000 MW baseload need. Again, the optimal mix of these resources was determined using Plexos for 10 different weather years to provide a range of weather-dependant portfolios that service the need at an acceptable percentage of load served. Three sets of resource options have been developed and costed to meet this need profile.

5.2 Dispatchable Resource Solutions

The first set of resource candidates used to solve the 2,000 MW Baseload Need Scenario was dispatchable, stand-alone resource options – CCGTs and SMRs. Once more, both resource types assume a 10 per cent overbuild to achieve 100 per cent of load served. As such, a total resource build of 2,200 MW of either resource is required to fully serve the identified need. These assumptions and resulting costs are provided in Table 5.

Table 5 | Gas and SMR Resource Solutions – Baseload Need Scenario

Resource	Capacity Need (MW)	System Overbuild Factor	Resource Build (MW)	Energy Need (TWh)	NPV 2024 – 2090 in $2024 Real in Billion	% of Load Served
CCGT	2,000	10%	2,200	17.5	28.2	100.00
SMR	2,000	10%	2,200	17.5	27.6 to 33.8	100.00

***NOTE:** No value of excess energy production is explicitly captured in these results; however, Section 6 discusses the implications of assigning excess energy a value.

At the low end of the range, the SMR generation solution is the most cost-effective stand-alone resource option and can service the 2,000 MW (and 17.5 TWh) baseload need at a cost of $27.6 billion to $33.8 billion. The gas-only option has a similar, though slightly higher, cost to the low end of the SMR-only range and can fully meet the need at $28.2 billion.

[11] Supply Mix and Generation

5.3 Hybrid Resource Portfolio Solutions

The next set of resource candidates used to solve the Baseload Need Scenario was hybrid resource portfolio options. The results of the Plexos simulation are presented in Table 6 below.

Table 6 | BESS + Wind + Solar Resource Solution – Baseload Need Scenario

Weather Year	BESS (MW)	BESS (MWh)	Wind (MW)	Solar (MW)	Total (MW)	Excess Energy (TWh)*	NPV 2024 – 2090 in $2024 Real in Billion	% of Load Served
1	1,816	18,046	6,101	4,343	12,261	11.0	39.2	99.68
2	1,350	11,825	7,390	2,579	11,318	15.7	37.8	99.93
3	1,949	19,491	6,757	3,523	12,229	13.9	39.5	99.78
4	1,686	16,857	7,857	3,527	13,069	16.8	41.3	99.93
5	1,794	17,938	9,700	3,601	15,094	25.6	46.8	99.86
6	1,737	17,370	7,826	2,062	11,625	17.4	39.5	99.91
7	1,860	18,602	6,806	3,349	12,015	13.0	37.3	99.77
8	1,418	13,439	7,454	2,026	11,826	15.9	40.1	99.91
9	1,833	18,328	8,471	2,840	13,143	20.4	38.8	99.87
10	2,260	22,604	7,015	2,644	11,920	14.6	40.2	99.87

***NOTE:** No value of excess energy production is explicitly captured in these results; however, Section 6 discusses the implications of assigning excess energy a value.

As before, the hybrid resource portfolio is very sensitive to the weather year selected. On a cost basis, if weather year 5 is used, approximately 15,100 MW is required to service the 2,000 MW baseload need at a cost of ~$47 billion. This can be contrasted with weather year 7, wherein approximately 12,000 MW is required to service the same need at a cost of ~$37 billion. Nonetheless, in all weather years, the stand-alone SMR is the least costly resource option compared with a hybrid resource portfolio, while also being able to serve all 100 per cent of the load.

5.4 Dispatchable + Hybrid Resource Portfolio Solutions

The final set of resource candidates used to solve the Baseload Need Scenario was dispatchable + hybrid resource portfolio options. This allows Plexos to select a portfolio of resources from the following candidates:

- Four-, six-, eight- and 10-hour duration BESS
- Wind

- Solar
- CCGTs
- SMRs

In this case, an SMR-only solution was selected for all 10 weather years. It should be noted that the low range of SMR costs was used as inputs into the model. An alternative scenario was also explored where the SMR was removed as a candidate resource. In this instance, the model selected a gas-only resource solution in nine of the 10 weather years.

5.5 Summary

The Baseload Need Scenario is based on a constant 2,000 MW need that translates into an energy requirement of 17.5 TWh per year. Three sets of resources were explored to meet the profile.

1. **Dispatchable Resources** – able to fully meet the need (100 per cent of load served), where the gas-only and the SMR-only options have similar costs of $28 billion to $34 billion, with the NREL-based SMR costs forming the lower bound.
2. **Hybrid Resource Portfolios** – meets the need in excess of 99.68 per cent of load served, with costs ranging from $37 billion to $47 billion, depending on the weather year used.
3. **Dispatchable + Hybrid Resource Portfolios** – able to fully meet the need (100 per cent of load served), where in all weather years a fully dispatchable resource option was selected.

No value of excess energy production is explicitly captured in these results; however, Section 6 discusses the potential implications of assigning excess energy a value. With a baseload energy need, it is evident that dispatchable resource solutions like SMRs provide the best value when tasked with meeting such a need.

6. Excess Energy

When using a capacity expansion model to build a cost-optimized portfolio of resources to meet an identified need, particularly in the case of intermittent resources like wind and solar, there will almost always be times where the available energy capacity of the resource mix exceeds the need. The production cost model will curtail the resources to the extent their hourly availability exceeds hourly load and the batteries are fully charged.

The amount of value assigned to this "curtailed generation" or "excess energy" can vary greatly. This section discusses the potential value of the excess energy that could be produced by VG under both the Peaky Need Scenario and Baseload Need Scenario.

6.1 Peaky Need Excess Energy

6.1.1 BESS + Wind + Solar (Hybrid Resource Portfolio)

Table 7 | BESS + Wind + Solar Excess Energy Value – Peaky Need

Weather Year	Curtailed Wind (TWh)	Curtailed Solar (TWh)	Total Excess Energy (MW)	Value of Excess Energy NPV 2024-2090 in $2024 Real in Billions
1	19.4	8.3	27.7	0 to 24.7
2	34.1	4.0	38.1	0 to 34.0
3	22.5	9.3	31.8	0 to 28.3
4	35.5	5.5	41.0	0 to 36.6
5	31.7	5.0	36.7	0 to 32.8
6	18.6	7.0	25.6	0 to 22.8
7	23.8	6.6	30.4	0 to 27.2
8	24.3	5.0	29.2	0 to 26.1
9	21.4	6.0	27.5	0 to 24.5
10	24.4	5.5	29.9	0 to 26.7

As can be seen from Table 7, there exists the potential for large amounts of value from excess VG. This all depends on the value assigned – on the low end, if a value of zero is assigned to this generation, there is no value to this energy. Conversely, at the high end, if we value this excess energy at the average forecasted market clearing price (from the 2025 APO), the value can exceed $36 billion, depending on the weather year used to meet the need.

6.1.2 BESS + Wind + Solar + Gas

Table 8 | BESS + Wind + Solar + Gas Excess Energy Value – Peaky Need

Weather Year	Curtailed Wind (TWh)	Curtailed Solar (TWh)	Total Excess Energy (TWh)	Value of Excess Energy NPV 2024-2090 in $2024 Real in Billions
1	7.7	1.5	9.2	0 to 8.2
2	13.8	1.0	14.8	0 to 13.2
3	12.1	0.5	12.6	0 to 11.2
4	10.0	0.8	10.8	0 to 9.6
5	8.1	0.7	8.8	0 to 7.9
6	10.0	1.4	11.4	0 to 10.2
7	8.8	1.3	10.1	0 to 9.0
8	9.5	1.0	10.5	0 to 9.4
9	7.5	1.6	9.1	0 to 8.1
10	9.5	0.6	10.2	0 to 9.1

Table 8 summarizes the value from excess VG when gas resources are included in the Plexos simulations as a resource candidate. As expected, the presence of gas greatly reduces the curtailed VG and, thus, the value of the excess generation. Again, on the low end, if a value of zero is assigned to the excess energy, there is no value to this energy. Conversely, at the high end, if we value this excess energy at the average forecasted market clearing price, the value can exceed $13 billion, depending on the weather year used to meet the peaky need.

6.2 Baseload Need Excess Energy

Table 9 | BESS + Wind + Solar Excess Energy Value – Baseload Need

Weather Year	Curtailed Wind (TWh)	Curtailed Solar (TWh)	Total Excess Energy (TWh)	Value of Excess Energy NPV 2024-2090 in $2024 Real in Billions
1	11.0	5.6	16.6	0 to 14.8
2	15.6	2.9	18.5	0 to 16.5
3	13.8	3.8	17.7	0 to 15.8
4	16.6	3.6	20.1	0 to 18.0
5	25.5	4.2	29.7	0 to 26.5
6	17.1	2.1	19.3	0 to 17.2
7	12.9	4.0	16.9	0 to 15.1
8	15.8	3.3	19.1	0 to 17.0
9	20.3	3.5	23.8	0 to 21.3
10	14.4	2.8	17.3	0 to 15.4

Table 9 summarizes the potential value from excess VG when these resources are used to meet a 2,000 MW baseload need. It is apparent that this system is substantially overbuilt, with excess energy ranging from 17 TWh to 30 TWh to meet a 2,000 MW (or 17.5 TWh) need. On the low end, the value of this excess energy can be assigned no value, and on the high end, the value of this generation can be up to $27 billion, depending on the weather year used.

6.3 Summary

When using a capacity expansion model to build a cost-optimized portfolio of resources to meet an identified need, there will be times where the available energy potential of the resource mix exceeds the load requirement plus BESS charging capability. This section attempted to value this excess energy for various sets of resource portfolios containing VG, after meeting the following need scenarios:

1. **Peaky Need Scenario** – depending on the price assigned to the excess energy – and weather year used – a hybrid resource portfolio could yield about $36 billion in excess energy

value. A hybrid resource + gas portfolio is better able to load-follow, so less value of excess energy (up to $13 billion) is captured in this resource mix.

2. **Baseload Need Scenario** – a hybrid resource portfolio could produce up to 30 TWh of excess energy with a value of $27 billion, again, depending on the price assumption and weather year used.

In summary, it is evident through this simplistic sensitivity analysis that excess energy generated through VG could potentially provide tens of billions of dollars in system value. This value needs to be considered in any planning study when comparing resource portfolios to meet a specific need.

Furthermore, detailed analysis is required to determine with more accuracy and precision the potential value of excess energy. This will become even more important as the IESO plans to explore opportunities for exporting excess energy.

7. Conclusion and Key Findings

This paper was the impetus for the IESO to explore new ways to model VG and BESS hybrid resource portfolios, ultimately building on the organization's modelling capabilities and thought leadership within the sector. The analysis framed two need scenarios to study the equivalency of VG-BESS hybrid resource portfolios. The Peaky Need Scenario resulted in an unserved energy profile of 5.1 TWh with a peak need of 7,311 MW. The Baseload Need Scenario resulted in a 2,000 MW baseload need profile, akin to a large baseload generation facility.

The capability and costs of hybrid resource portfolios to meet defined need profiles were compared with CCGT and SMR options to meet the equivalent needs. The main takeaways are described below.

7.1 Key Findings and Implications:

7.1.1 Hybrid Resource Portfolios Can Meet Need in Simulations

Under both the Peaky Need Scenario and the Baseload Need Scenario, a portfolio of VG + BESS was able to supply the need profiles, under all weather years, with 99.50 to 99.98 per cent of load served (as described in Section 3.4.4). This study did not impose build limits on any technology type and the installed capacity required, and costs associated with hybrid resource portfolio solutions were in the range of 1.5 to two times that of the gas or SMR options.

The premium on installed capacity and costs of hybrid resource portfolio solutions required to achieve load served up to 99.98% was smaller than expected. This is likely due to the diverse wind and solar profiles across various sites in the province which was enhanced by the copper plate system (i.e. the study assumed zero transmission constraints), as well as the enhanced performance of newer wind and solar technologies, which is reflected in the weather profiles. Furthermore, this study did not consider the supply chain and labour limitations or other factors that could impact the feasibility of constructing such resource portfolios.

Implications: As performance of VG and BESS technologies improves and costs continue to decline, a non-emitting, hybrid resource portfolio, in theory, shows significant promise. It can provide both baseload and peak power with reasonably high, albeit imperfect, reliability, and potentially at costs that are competitive with gas and nuclear generation. Additionally, there appears to be value in geographic diversity when considering VG technologies from a reliability perspective.

7.1.2 Optimized Hybrid Resource Portfolio + Gas the Best to Meet a Peaky Need

The least-cost resource option to meet the 5.1 TWh Peaky Need Scenario was the optimized VG + BESS + gas portfolio. This option cost between $25 billion and $34 billion, depending on the weather year used (NPV 2024-2090 in $2024 real dollars). This option was less costly than the gas-only resource option (~$31 billion) in seven of the 10 weather years utilized.

Implications: A portfolio of resources that includes a combination of gas generation, VG and BESS is best suited to meet a peaky need profile. This resource mix was the cheapest option and could serve 100 per cent of the load.

7.1.3 Dispatchable Resources the Best to Meet a Baseload Need

The least costly resource option to meet the 2,000 MW Baseload Need Scenario is a dispatchable resource option. The SMR-only option costed $27.6 billion to $33.8 billion (depending on the cost benchmark used), while the gas-only option costed ~$28 billion. Both options met 100 per cent of the load. The non-emitting hybrid option costed between $37 billion to $47 billion depending on the weather year, which corresponds to a levelized cost of energy range of approximately $140/MWh to $175/MWh.

Implications: dispatchable resource options are best suited to meet baseload needs such as the 2,000 MW Baseload Need Scenario defined in this study. Both SMR-only and gas-only resource options have similar cost profiles when acting as a baseload generator.

7.1.4 Excess Energy and its Value

The value of excess electricity generation from VG was not explicitly captured in the modelling results of this study but was discussed at a high level. Potentially substantial value of excess energy produced from VG-based resource portfolios to meet both a peaky and baseload need may be achieved, but the magnitude of the value depends on how this excess energy is priced.

Implications: Given their intermittent nature, VG-based resource portfolios often need to be overbuilt to meet system adequacy requirements. Of course, if the system is overbuilt, there will be times when generation exceeds what is required to fully serve the load. This value of excess energy needs to be considered in any planning study when comparing resource portfolios to meet a specific need. More detailed analysis on valuation of excess energy is needed to achieve higher accuracy and precision.

7.1.5 Immediate Applications of Modelling Techniques

As discussed earlier in this paper, the modelling techniques developed for this study are most reliable when applied to simple systems. For instance, the IESO has uses similar techniques to develop non-emitting resource portfolios as non-wires alternatives in regional and bulk system plans, where appropriate. This approach is effective when the local system needs can be reasonably represented by an 8,760-hour profile.

However, with larger study scopes there is more complexity, and 8,760 profiles can no longer reasonably represent the system of interest. This is especially true as more existing, dispatchable resources are to be considered in the study scope, as their dynamic operations cannot be adequately capture in deterministic profiles.

7.2 Next Steps

To improve on the IESO's hybrid modelling capabilities and other such analysis, and to better inform any future procurement activities to help meet Ontario's increasing electricity demand, the following next steps will be considered as an extension of this study:

- **Solicit Feedback from Industry Partners:**
  The IESO will solicit feedback from the study and work with industry partners to improve methodologies to better incorporate VG and BESS into future planning activities, including a possible next phase of this technical paper.

- **Re-run the Simulation Based on Updated Need Profiles:**
  As mentioned earlier in this paper, the Peaky Need Scenario is based on *preliminary* energy simulations for the 2025 APO. At the time the analysis was conducted, the final 2025 APO results were yet to be finalized. A next phase(s) of this technical paper could involve re-running the model to with the most up-to-date Ontario need profiles.

- **Run Portfolios Developed in this Study through the IESO's APO Models:**
  An interesting next phase of this technical paper would involve taking the resource portfolios developed here and running them through the full system models used for the APO. This would provide a more detailed and dynamic representation of how these resource mixes interact with the rest of the provincial system. Additionally, this could enable a more robust and defendable valuation of the excess energy generated by the hybrid resource portfolios.

- **Inform Future Procurement Activities**
  It is anticipated that modelling approaches such as those used in this technical paper can eventually help inform future procurement activities. By adopting new capacity expansion modelling techniques to meet defined system needs, system resources portfolios can be further optimized to more cost-effectively achieve reliability criteria and decarbonization targets.

Appendix 1 – Levelized Costs of Resource Candidates

See separate Excel file

Appendix 2 – Peaky Need Scenario Profile and BESS Charging Capabilities

See separate Excel file

Appendix 3a – Wind Profiles

See separate Excel file

Appendix 3b – Solar Profiles

See separate Excel file

Appendix 4a – Detailed Plexos LT Modelling Results

See separate Excel file

Appendix 4b – Detailed Plexos ST Modelling Results

See separate Excel file

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